

Instrument Performance of AIRS

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Abstract

AIRS, the Atmospheric Infrared Sounder on the Earth Observing System (EOS) PM spacecraft, is an infrared radiometer which covers the 3.7 - 15.4 micron spectral range with spectral resolving power better than 1000. Performance of the AIRS flight unit will be discussed based on measurements in a thermal vacuum test and calibration facility. Simulated data, based on measured instrument performance and GCM model data, indicate that AIRS, together with the AMSU and HSB microwave radiometers on EOS PM, will achieve retrieval accuracy better than 1K rms in the lower troposphere under clear and partly cloudy conditions. Launch of AIRS on the EOS PM is scheduled for December 2000.

1. Introduction

The requirement to achieve radiosonde equivalent accuracy under operational conditions, typically stated as 1K rms accuracy in 1 km thick layers, using remote sensing from low-earth-orbit is a challenge to retrieval algorithms and to the designers of infrared sounders. One of the main complications in achieving the 1K/1km requirements is the almost universal presence of clouds and haze equivalent to 10% cloud cover. AIRS, a Pupil-imaging Grating Spectrometer which covers the 3.7 - 15.4 micron spectral range with 2378 independent spectral channels with spectral resolving power of 1200, provides two order of magnitude more spectral information content than HIRS/2 in the TOVS series (1). AIRS, together with the AMSU-A and HSB (Humidity Sounder of Brazil, made in collaboration between the Brazilian Space Agency and the prime contractor of the AMSU-B), is expected to operationally achieve retrievals with radiosonde accuracy in the presence of clouds. A copy of AMSU-A and AMSU-B are currently in orbit on NOAA-K. The launch of AIRS, AMSU-A and HSB on the EOS PM is scheduled for December 2000.

In the following we briefly review infrared sounder performance considerations in general and additional requirements related to sounding in the presence of clouds. We then discuss results from the AIRS instrument flight unit and data processing considerations.

2. Infrared Sounder Performance Requirements.

In order to achieve radiosonde equivalent accuracy, interpreted as 1K rms accuracy in 1km layers below 100mb and in the presence of partly cloudy fields of view, generally accepted performance requirements include

- a) spectral coverage from 3.7 to 15.4 microns with spectral resolving power of the order of 1200. This includes the 4.2 and 15 micron CO₂ bands and super window channels and weak water lines in the 3.8 micron region to aid the determination of boundary layer water vapor. The spectral sampling has to satisfy the Nyquist sampling requirement to allow arbitrary resampling of spectral channels.
- b) system sensitivity, usually expressed as noise equivalent temperature difference, NEDT=0.2K at 250K.
- c) spatial coverage adequate to support weather forecasting, usually interpreted as soundings on a 50km grid, with FOV of 10 - 15 km diameter, coaligned with a microwave footprint.

The system sensitivity requirement refers to the total system noise. In addition to fundamental detector noise significant instrument related contributions to the system noise are scene dependent spatial co-alignment and spectral calibration effects. The random error in the radiative transfer calculations used in the retrieval software places a practical noise floor at NEDT=0.1K.

- a) Since the retrieval algorithm assumes that the measured spectral radiances refer to the same vertical column, all spectral channels must be accurately co-aligned. It can be shown that for a FOV with 50% fractional cloud cover a 2% misalignment of the spatial response function correspond to brightness temperature error of the approximately 0.14K. At 5% misalignment the error increases to 0.4K rms. Co-alignment to within 1% of the FOV is desirable. For HIRS/2 on the NOAA-K all 19 channels are co-aligned within 2% of FOV.
- b) Gradients in the scene illumination, for example due to high contrast cold or hot (during daytime at the short wavelengths) clouds, can create uncertainty in the spectral response function (SRF) centroid position and shape. The resulting brightness temperature uncertainty will not be distinguishable from random noise, although its character may not be gaussian. With spectral resolution of 1200 an SRF position or width uncertainty of 1% of the width is equivalent to a 0.2K error in regions of high spectral contrast, such as in the $690 - 720 \text{ cm}^{-1}$ region and near the center of the R-branch at 2382 cm^{-1} .

In the following we discuss the performance measured for the AIRS flight model relative to the above discussed performance considerations.

3. AIRS Flight Model Sensor System Test Results

AIRS is a pupil imaging, cross-track scanning spectrometer (2). Global spatial coverage is obtained by cross-track scanning, i.e. by rotating a 45 degree scan mirror at the rate of 1.06 degree / 0.022 sec from +49.5 to -49.5 degrees perpendicular to the spacecraft velocity vector. Pupil imaging combined with scanning assures a high degree of scene illumination independence of the SRF. The AIRS spectrometer is radiatively cooled to 155K. The AIRS detectors are cooled with an active Sterling type pulse-type cooler to 58K. Combination of low background and photon noise limited arrays gives the AIRS grating array spectrometer a multiplex advantage and is key to the achievement of very high sensitivity. Testing of the AIRS flight model in the AIRS Test and Calibration Facility (ATCF) started at the end of March 1999 (3). The final calibration phase is scheduled to be completed by June 1999 In the following we present results of AIRS flight model tests completed in January 1999 and discuss how the results compare to the requirements and the general sounder design considerations.

a. AIRS spectral coverage from 3.7- 15.4 microns and spectral resolving power are shown in Figure 1. Spectral resolving power ranges from 1100 to 1500, depending on wavelength. The spectral calibration uses a Fourier Transform Spectrometer (Bruker IFS 66V). The signal from a blackbody, modulated by the FTS as function of the optical path difference (OPD), is measured simultaneously on all 2378 AIRS detectors. In order to eliminate polarization, self-emission and illumination effects, the signal from the FTS is scrambled in an integrating sphere before it is projected onto the AIRS entrance pupil.

b. Detector Sensitivity: The sensitivity of all AIRS channels, expressed as the noise equivalent temperature difference NEDT, is measured simultaneously by measuring the radiometric gain and the noise of each channel. Figure 2 shows the NEDT for all channels, referred to the typical 250K scene temperature. The median NEDT is 0.1K. 90% of the spectral channels have NEDT of better than 0.2K. The NEDT of 0.05K and less in the mid-band region comes as a "free" consequence of cooling the spectrometer to 150K and operating the detectors at 58K in order to meet the sensitivity requirement in the key 4.2 micron and 15 micron temperature sounding regions.

c. Spatial Response: The static spatial response function of AIRS was measured simultaneously for all detectors by raster scanning the field of view with a 0.1 degree diameter source in 0.07 degree steps. The 0.1 degree diameter source was imaged by a spatial collimation system to appear at infinity in front of a 2.5 degree diameter 140K cold background. The measured radiometric diameter of the field of view was 1.06 degrees. Figure 3. show the distances of the radiometric centroids of all channels in degrees as function of wavelength from the mean centroid. More than 60% of the channels, including all key sounding channels are within 0.02 degrees of the common centroid. Since the FOV diameter is 1.06 degrees, this corresponds to a spatial co-alignment within 2% of the FOV.

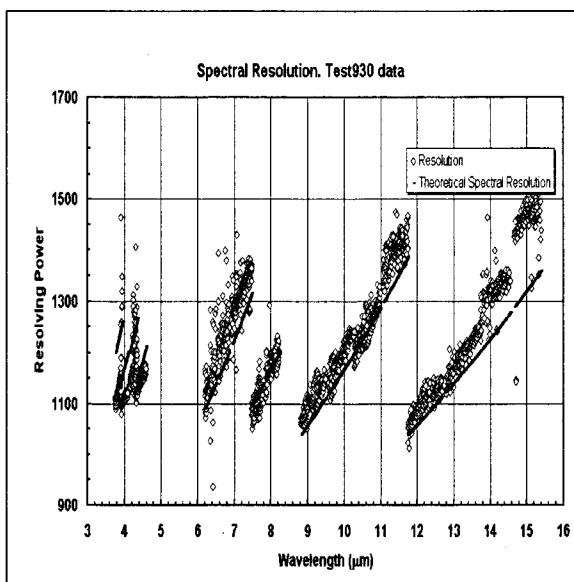


Figure 1. AIRS measured resolving power (wavelength/full width at half peak of the SRF) as function of wavelength. The solid line is the required design resolving power.

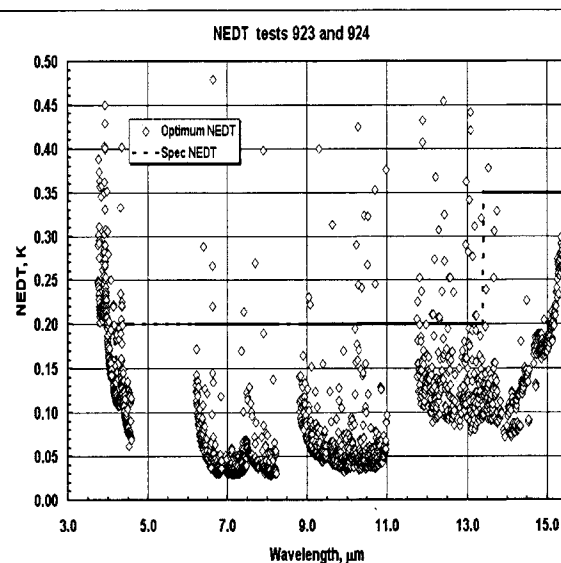


Figure 2. Detector NEDT for all channels, referred to 250K scene temperature exceeds the requirement (solid line) at most wavelengths.

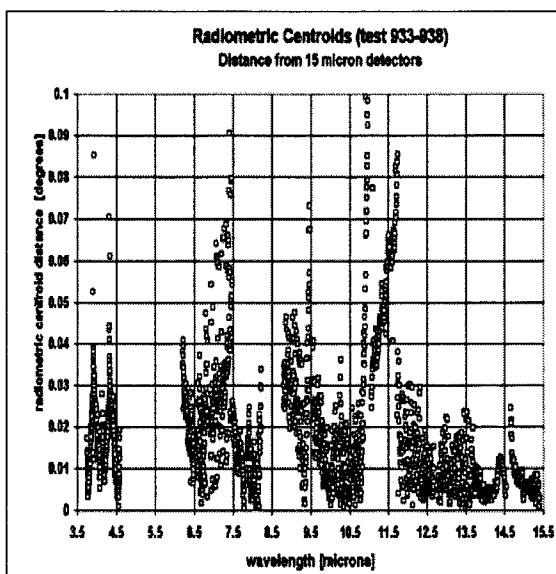


Figure 3. More than 60% of the radiometric centroid of all AIRS channels are located within 2% of the FOV diameter.

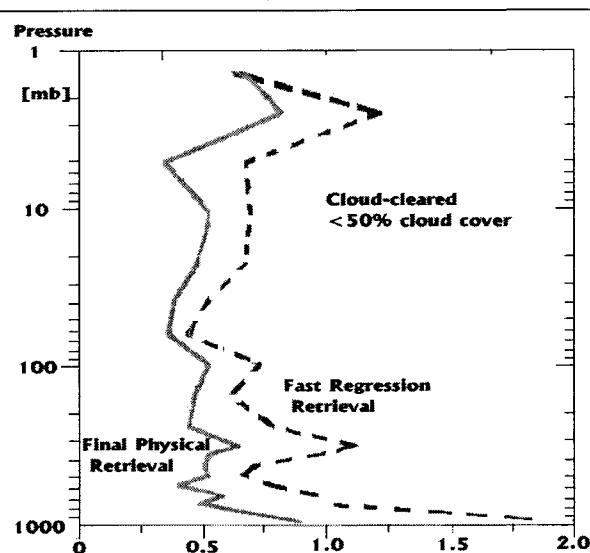


Figure 4. Retrieval accuracy [degree K rms] in the troposphere under cloud clearable conditions

4. Data Product Generation System (PGS)

Data processing for the AIRS/AMSU/HSB system has been developed through an intensive data simulation effort, including realistic cloud effects. Experimental NOAA Global Circulation Models (GCM) were used to calculate the upwelling spectral radiance measured from Earth orbit. The data simulation assumes a contribution of 0.14K on each spectral channel from sources of noise in addition to the random detector NEDT. This is consistent with 2% FOV misalignment in the presence of 50% cloud cover and a 0.1K

contribution from the radiative transfer algorithm. Fractional cloud-cover, cloud height and cloud liquid water content are based on the GCM. Surface emissivity is based on AVHRR maps of the date of the GCM run. These simulations are currently being refined based on the measured instrument performance.

The operational data processing is done by the PGS. After the conversion of the raw data (level 1a) to calibrated radiances (level 1b), the PGS generates the temperature and moisture retrievals based on the combination of 9 AIRS footprints, 9 HSB footprints, all centered on one AMSU-A footprint, with sequential refinement of the solution. The major steps in the temperature and moisture profile retrieval are:

- 1) Retrieval using microwave channels only.
- 2) Shift to the standard frequency set and common slant angle centered on the AMSU footprint.
- 3) First pass cloud clearing and generation of cloud-cleared radiances.
- 4) Calculate the tuning vector
- 5) Retrieval using fast regression (First product generation)
- 6) Second pass cloud clearing
- 7) Retrieval using physical retrieval (Final product generation). This step includes temperature, moisture, cloud-height, cloud fraction and surface emissivity error estimates for each retrieval.

Details of the instrument calibration and retrieval algorithms have been published in Algorithm Theoretical Basis Documents (4). Figure 4 shows temperature retrieval results (5) from step 4 (fast regression) and the significant improvement with the physical retrieval in step 6 under mid-latitude and cloud-clearable conditions using simulated data. Actual cloud cover in the individual FOV's ranged from 10% to 50%, with no clear FOV's. Retrieval accuracy using the physical retrieval procedure, with the fast statistical retrieval as initial solution, is better than 0.6K rms in the lower troposphere.

The PGS has to keep up with the data. Since there are 30 AMSU-A footprints per scan line of 8 second duration, retrievals have to be processed at the minimum rate of 260 msec per retrieval. Current estimates indicate that four SGI /R10000 class processors in coarse grain parallel processing mode can produce the calibrated radiances, cloud-cleared radiances and the first retrieval products and keep up with the input data flow. The estimated computing power required to keep up with the final product generation, including factor of two margin for reprocessing, is 128 SGI/R10000 class processors.

5. Summary

Based on the measured instrument sensitivity, spectral and spatial performance, and the performance of the PGS software, AIRS, together with the AMSU and HSB microwave radiometers, are expected to achieve operational retrieval accuracy better than 1K rms in 1km thick layers in the troposphere under clear and partly cloudy conditions.

6. Acknowledgements.

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7. References

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